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Constructing Interlinked Learning Resources for Integrated STEM Education Environment

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Abstract: The integration of STEM disciplines is increasingly advocated because it is one way to make learning more connected and relevant for students. How discipline integration can be achieved are varied, with reference to multidisciplinary, interdisciplinary, and transdisciplinary approaches adding to the debates. In integrated STEM education environment, teachers and students need to analyze and synthesize the learning content themselves through e.g. examining complex problems, using a variety of means and developing their own strategies to solve these problems. During this learning process, an explicit, well-organized and easy-to-reference learning resources will support the learning effectively. This paper focuses on how to organize learning resources for different integrated STEM pedagogical methods and learning tasks. Employing the idea of Web of Data and Linked Open Data, we describe the learning resources by semantic annotations understandable to both human and machines, and interlinking relevant resources according to the learning tasks and pedagogical methods. A user friendly resources searching, accessing, and visualization form in integrated STEM environment is also presented. By analyzing the goal and content of learning, an ontology is designed to represent the body of knowledge in STEM education, so the knowledge point in STEM education can be described by vocabularies in the ontology. These vocabularies serve as semantic tags for learning resources. We attach appropriate semantic tags to every learning resource by employing semantic annotation methods, and the learning resources will be organized and interlinked well according to their content and semantic information. Learners will take advantage of this content-based resources structure and improve the learning performance. Because we adopt standard data representation techniques, such as RDF, OWL and SPARQL etc., it will be convenient to implement and deploy the resources organization architecture in learning environment. We design a comparative experiment between semantic interlinked learning resources and non- semantic organized learning resources. Because of the support of semantic tag, it is easier to perform content-based semantic retrieval on semantic interlinked resources. From the aspects of student self-efficacy and learning achievement goals, we prove the effectiveness of interlinked learning resources organization proposed.

Keywords: STEM Education, Learning Resources, Resource Integration, Semantic Annotation, Ontology

1. Introduction

As modern education pays more and more attention to the integration of disciplines, the emergence of STEM education promotes this trend. It not only promotes students' understanding of various subjects but also enriches teaching content. In this process, teachers and students are faced with multi-disciplinary and inter-disciplinary learning, which makes the learning resources they are exposed to soaring. Therefore, effective learning resource organization becomes very necessary. The essence of learning resource organization is to solve the problems of fragmentation, lack of system, and relevance of network resources. Many valuable online course resources have not been effectively organized, and learners have lost their way in the huge system resource library. The emergence of diversified learning resources in STEM comprehensive courses will not necessarily improve teaching efficiency, but it can easily lead to resource confusion, thereby affecting its effective sharing and organization. Therefore, the scientific organization of learning resources is conducive to the effective use of digital learning resources [1]. This research focuses on the integrated STEM education environment and proposes a "framework of interlinked learning resources". Teachers and students use the framework to analyze and integrate learning content, use Protege to organize clear learning resources, and carry out corresponding teaching experiments. From project construction ideas, students' self-efficacy and learning achievement goals have verified that the framework can effectively support learning.

2. Related Work

In recent years, more and more attention has been paid to the study of learning resource organization. People try to straighten out the complex relations of the resources using ontology and the semantic web.

Jian Qin elaborated on the knowledge organization method of library and information science, thinking that ontology is a special knowledge organization system that combines vocabulary-controlled methods, coding expressions, and reasoning methods to deal with the increasing number of digital data and information [2]. Bahadir Namdar and Ji Shen and others designed a platform to link knowledge items based on similar keywords, and used a hybrid method to analyze individual entries and knowledge base, to determine the knowledge organization at individual and collective levels [3, 4].

Zeng Wen et al. propose a knowledge organization system framework of scientific literature data resources. Starting from the basic elements of the knowledge organization system, a term-based scientific literature analysis method and technology are designed. Construct a knowledge organization system according to a specific structure, and realize semantic-based retrieval through classification and indexing. And through the description and organization of information data to support semantic understanding, standardization, and information resource retrieval [5, 6].

Pilar Escobar, Gustavo Candela, and others have defined a framework based on the entire lifecycle of data publication including a novel step of Linked Open Data assessment and the use of external repositories as a knowledge base on data enrichment. Users can interact with the data generated according to the RDF Data Cube vocabulary, which makes it possible for general users to avoid the complexity of SPARQL when analyzing data [7]. Yolanda Blanco-Fernández, Alberto Gil-Solla, etc. want to fight information overload by semantics-driven filtering and knowledge generation, proposed a new way of learning History based on natural language processing and Linked Data. They customize text collection to train neural networks and examine user knowledge and use word vectors to find and evaluate relevant interconnections between semantic entities [8, 9].

Wang Xiaogen, Deng Liejun and others proposed a mobile learning resource organization model based on knowledge elements "extraction-indexing-linking-representation", which dynamically represents the attributes of knowledge elements. Based on the knowledge element of organizational learning resources, can help learners to improve learning efficiency, establish a comprehensive system of knowledge, promote innovation and knowledge [10, 11].

Apoki Ufuoma Chima proposed a framework for personalized learning – WASPEC. This is accomplished with the combined use of web services, semantic web ontologies, and pedagogical agents, providing dynamic personalisation in the background of the e-learning system [12].

Ceciliaavila-Garzon discovers that most semantic network research is concentrated in the use of technology and tools, which are used in the fields of biology, social science, book management and education [13]. But these research is difficult to apply directly in education teaching. However, these studies provide theoretical basis for the integration of learning resources.

3. Framework of Interlinked Learning Resources

3.1. Method

For the subject STEM integrated curriculum, this paper designs an ontology-based resource framework construction model so that teachers and students can use semantic markup methods to mark the learning resources required by the subject project according to the model, organize and link these resources. And a user-friendly resource search, access and visualization structure diagram were proposed. The premise of using this model is that the learning resources are sufficient but messy and lack of integration. Teachers should have certain ontological knowledge and set up a link map of learning resources for students to use when preparing lessons before class, to improve the learning effect of students.

3.2. Basic Organization of the Framework

This paper designs a learning resource organization and construction model, which can be summarized as the following seven steps (e.g., Figure 1).

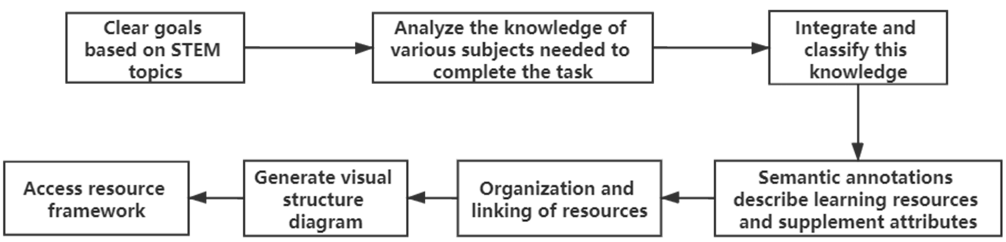

Figure 1. *Basic framework of resource organization.*

Clear goals based on STEM topics. In the process of analyzing topics closely related to real life, students can not only learn knowledge, but also acquire the ability to use knowledge flexibly to solve practical problems and have the ability to infer each other. The choice of topics is usually expandable, open and flexible, and at the same time focused, so that students can master knowledge without restricting their personality development. For example, "build a greenhouse environment suitable for the growth of roses", the task is to build a greenhouse, which is a greenhouse suitable for the growth of roses, which limits the scope.

Analyze the knowledge of various subjects needed to complete the task. After clarifying the subject and task, by decomposing the task, list the learning resources needed to complete the project, such as upper-level knowledge, project-related field knowledge, and expanded knowledge. Corresponding to the theme of "Building a Greenhouse Environment Suitable for Rose Growth", the upper-level knowledge includes mathematics length measurement, etc.; project-related field knowledge includes the concept of greenhouses and greenhouse construction, etc.; expanding knowledge includes understanding the work of agricultural scientists.

Integrate and classify the knowledge of various subjects. After completing the collection work, it is necessary to integrate the learning resources into a resource frame diagram, and classify them according to the four major categories of Science, Technology, Engineering and Mathematics. Among them, Science mainly includes the knowledge of natural laws; Technology refers to the means to solve practical problems, including a selection of materials, tools, etc.; Engineering refers to the preparation of problem-solving procedures, including preliminary design, prototype modification, etc.; Mathematics is the measurement of data in the process of solving problems, the description of mathematical relations, etc. In the "Building a Greenhouse Environment Suitable for Rose Growth" project, a classification example can be made (e.g., Table 1).

Table 1. *Classification of learning resources.*

Science	Technology	Engineering	Mathematics
Features and functions of greenhouse	Build materials	Greenhouse design method	Length measurement and expression
Rose growing conditions	Build tools	Greenhouse test method	Mathematical estimation of objects
The growth cycle of roses	Build process	Understanding the work of agricultural scientists	-----
Rose cultivation method	-----	-----	-----

Semantic annotations describe learning resources and supplement attributes. After finishing the classification of the learning resources, use the ontology construction tool Protégé 5.0 to complete the learning resource frame diagram. When establishing this framework, we need to have a method of determining the ontology. First, when facing realistic theme scenes, we abstract the things in the theme as classes, as the ontology in the framework, that is, the apex of the framework. The relationship between the two is abstracted as edges; secondly, analyze which attributes each type has and where the attribute values come from. In this process, we can classify according to the previous step, from four aspects: S、T、E、M that each category defines an attribute set; finally, determine which associations exist on individuals, which attributes are in these associations, and what is the basis of the associated data. Therefore, under the same theme, different students will select different classes and individuals, and abstract different attributes. The learning resources obtained by each student are diverse, which helps to achieve personalized teaching.

Organization and linking of resources. We use the semantic labeling method to add corresponding semantic tags to each learning resource, and organize and link according to the content and semantic information of the learning resource. That is, establish annotation associations for the established ontology framework, link related resources with ontology, and improve the framework diagram of learning resources.

Generate a visual structure diagram. After establishing the object attributes and their associations, use the OntoGraf ontology diagram module in the protégé software to visualize the established learning resource framework diagram, and choose different visualization forms. It can effectively achieve the establishment of a user-friendly learning resource framework in the resource-rich STEM integration environment, effectively avoiding any load on students.

Access resource framework. We can access a query environment that supports content/semantic-based queries. In this environment, you can directly enter the content of the query, the visual interface will display the search content and its belonging relationship, or you can use the DL Query class to query. While establishing a visual resource block diagram, user-friendly resource search and access are realized, which is convenient for students to integrate and summarize learning resources.

When constructing a learning resource framework for each different topic, attention should be paid to choosing appropriate resources to avoid overloading with knowledge, which will affect students' sense of self-efficacy. This requires teachers to give students appropriate prompts when guiding students to analyze topics, and closely integrate learning resources required for the project.

Besides, after the learning resource framework is established, teachers should match the students' learning starting point and learning mode to prevent students from lacking a complete project plan, which will affect students' learning effects. At the same time, different students have different learning foundations. For students with higher abilities, they are encouraged to increase their learning in expansion, to better promote personalized teaching [14].

3.3. Implementation of the Framework

We have developed a resource organization framework using Protégé. Protégé software is an ontology editing and knowledge acquisition software mainly used for the construction of ontology in the Semantic Web [15]. Based on the framework proposed in section 3.1, we build an ontology-based learning resource organization. Vocabularies of concepts and data properties are used to annotate and label resources, object properties connect and link the related resource.

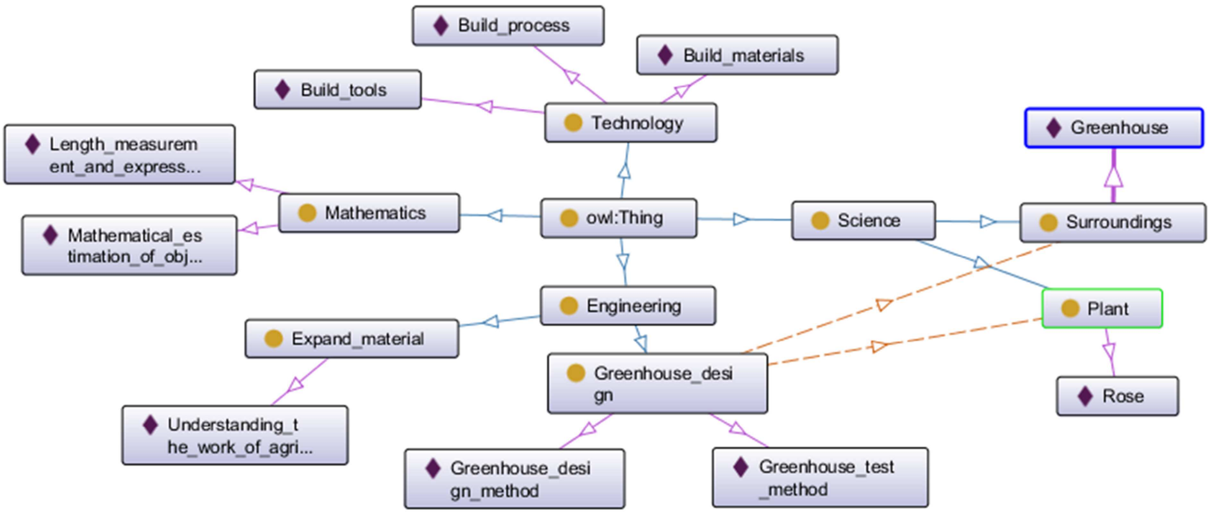

Figure 2. *Resource framework diagram.*

By protege, we can define classes, object properties, data properties and individuals used in describing learning resources. Classes are a collection of individuals, individuals can be understood as the instantiation of a class, or a member of a class, such as Class Plant, which can be a collection of roses, etc. In a class, you can create subclasses, you can create sibling classes, etc., such as Greenhouse_design is the subclasses of Engineering. Science, Technology, Engineering, and Mathematics are sibling classes to each other (e.g., Figure 2). SubclassOf, Equivalent, and Disjoint are the three axioms of classes, which can be understood as the relationship between classes. And Object Properties can be used to link two separate parts, such as Greenhouse_design in accordance with Surroundings (e.g., Figure 3). It is worth noting that the properties of Data Properties cannot be transitive, symmetric, or inverse functional, but can only be functional.

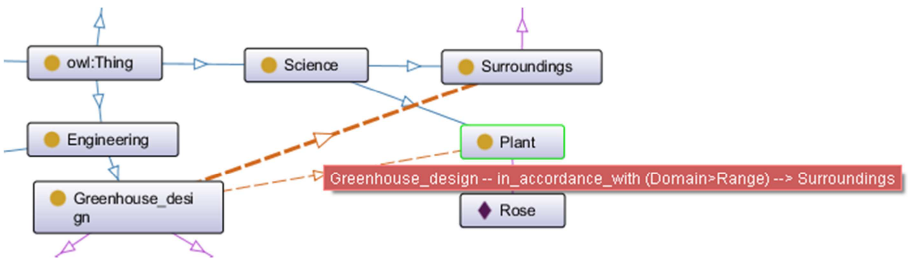

Figure 3. *Description of the relationship between resource.*

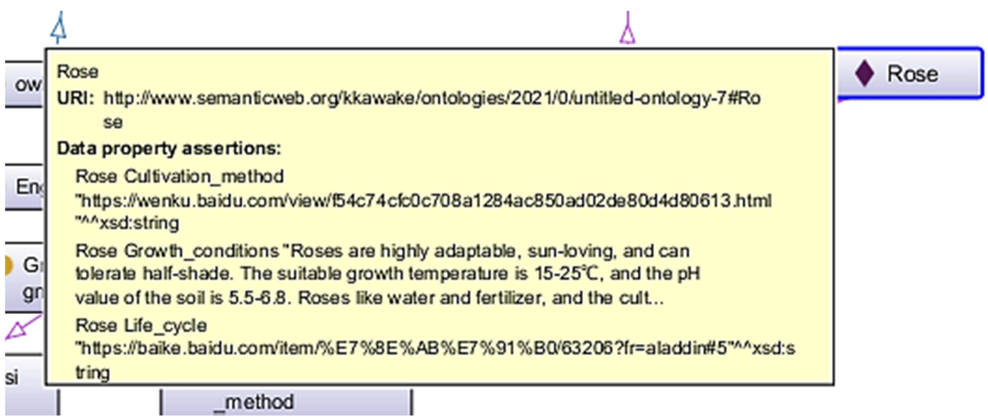

Figure 4. *Individual resource description.*

Domains and Ranges can be set in Object Properties, mainly for reasoning. Of course, you can also use subPropertyOf to create sub-properties, can also annotate properties, and can define the properties of object properties, such as Functional, Inverse functional, Transitive, etc. You can also add Data Properties in the software, which is used to connect individual and XML Schema data type values or RDF literal (e.g., Figure 4).

After the relationship is created, DL Query is used for querying, and OntoGraf can display a visual ontology relationship diagram. When saving the relationship diagram, it can be saved in RDF or OWL format for easy viewing next time (e.g., Figure 5).

```
<Class IRI="#Plant"/>
<NamedIndividual IRI="#Rose"/>
<Literal>https://wenku.baidu.com/view/f54c74cfc0c708a1284ac850ad02de80d4d80613.html</Literal>
</DataPropertyAssertion>    <DataPropertyAssertion>
<Annotation>          <AnnotationProperty abbreviatedIRI="rdfs:label"/>
<Literal>https://baike.baidu.com/item/%E6%B8%A9%E5%AE%A4/2824564#2_6</Literal>
</Annotation>
<DataProperty IRI="#Growth_conditions"/>
<NamedIndividual IRI="#Rose"/>
<Literal>Roses are highly adaptable, sun-loving, and can tolerate half-shade. The suitable
growth temperature is 15-25℃, and the pH value of the soil is 5.5-6.8. Roses like water and
fertilizer, and the cultivation substrate requires soil with good permeability and rich
organic matter.</Literal>
</DataPropertyAssertion>    <DataPropertyAssertion>
<DataProperty IRI="#Life_cycle"/>      <NamedIndividual IRI="#Rose"/>
<Literal>https://baike.baidu.com/item/%E7%8E%AB%E7%91%B0/63206?fr=aladdin#5</Literal>  |
```

Figure 5. *Excerpts from OWL format files.*

4. Application

To explore the impact on the construction of interconnected STEM educational learning resources proposed to this paper on STEM project learning, we designed a comparative experiment of semantic interconnected learning resources and non-semantic organization learning resources. There are two main objectives of this experiment. First, explore the influence of building semantics and learning resources on students 'self-efficacy and learning achievement goals; secondly, explore this method in the teaching process, and use teachers to assist students' personality Learning and knowledge iteration.

In this experiment, students in the first grade experimental class of Pingyao No. 1 Middle School in Jinzhong City, Shanxi Province are selected as the research objects. Their academic performance is in the middle stage of the class, and they have good thinking and learning abilities. A total of 10 people are divided into two groups. Before the experiment, the two groups were pre-tested. The pre-test content was "How to prevent indoor chemical gas pollution caused by decoration". The two groups of students described their design ideas and specific implementation plans. Then organize learning resources and teach related software Protégé to the experimental group to ensure that the differences within the group are minimized. In the next week, the two groups were subjected to subject-based STEM project experiments. The two groups of students respectively elaborated their respective plans and their project learning content according to the theme.

Table 2. *Average score of two groups.*

	Control group (average score)	Experimental group (average score)
Interpretation project (20 points)	15.2	15.8
Project construction ideas (20 points)	13.6	15.6
Subject knowledge analysis (20 points)	14.2	14.8
Student self-efficacy (20 points)	15.4	16.4
Learning achievement goal (20 points)	14.8	15.2
Total score (100 points)	73.2	77.8

The experimental STEM projects are related to a certain extent, namely "Building shading settings", "Campus surveying and modeling", "Simulating ecosystem", "Designing water purification system", and "Building solar system model". The experimental group established semantically interconnected learning resources, while the control group used non-semantic organizational learning resources to compare the scores of the two groups from the following five aspects (e.g., Table 2). Add the scores of each part of the team members' five projects and calculate the average score.

The experimental results show that, in the case of the same ability to understand the project, the experimental group mastering the resource integration method is better than the control group in the following aspects: project construction ideas, students' self-efficacy and learning achievement goals. And compared with the test results before the experiment, the experimental group has made significant progress, especially in the later period of the experiment, the knowledge linking ability of the experimental group is better than the control group. The experiment proves the effectiveness of interconnected learning resource organization for students in subject STEM learning.

5. Conclusion and Further Work

With the development of STEM integrated courses, the learning resources faced by students in their studies have increased from both breadth and depth. The research of Siadaty, M. et al. showed that semantic technologies can offer important advantages to workplace learning, once they are applied on top of sound pedagogical and motivational principles [16].

This paper combines the concept of data network and linked open data, describes learning resources through semantic annotations that humans and machines can understand, and interconnects related resources according to learning tasks and teaching methods. Combining with ontology, it builds a learning resource framework suitable for individual learners and proves that using this resource framework can more easily perform content-based semantic retrieval on semantically linked resources, and at the same time proves the effectiveness of interconnected learning resource organization.

However, the study has not confirmed whether the framework applies to other types of integrated STEM courses. Due to time and reality constraints, the research objects used in this experiment are experimental class students with strong learning abilities. Whether it is helpful for other students' learning effect needs further research. In future research, the author will conduct in-depth research on the teaching mode matched by the framework and continue to improve the framework.

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